Chapter 16 SOLIDS

⇒ There are four (4) states of matter;

1) Solid
2) Liquid
3) Gases
4) Plasma

⇒ *Some properties of these states of matter is given in the following table;*

Property	Solid	Liquid	Gases
Shape	Definite	Not definite	Not definite
Volume	Definite	definite	Not definite
Compressibility	Incompressible	Solids < Compressibility < Gases	Compressible
Crystallinity	Crystalline	Non-crystalline	–
Density	Maximum	Solids > Density (liquid) > Gases	Minimum
Relation between kinetic energy and potential energy	$k.e < P.E$	$K.E > P.E$	$K.E \gg P.E$
Interatomic/intermolecular distance	Constant	Not constant	Not constant
Effect of temperature	There are some specific range of temperature for substances to melt.	Temperature can affect liquid more than that of solid	Temperature can affect gases more than that of solid and gases
Freedom of motion	One-dimension motion	One- or two-dimension motion	More than two-dimension motion
Intermolecular force	Solid >Liquid>Gases	Liquid>gases	Gases<liquid<solids

⇒ The fourth states of matter i.e. Plasma is in the form of positive and negative ions and usually found in the atmosphere of stars or at discharge tube where high temperature is applied and atoms are converted into their positive and negative ions. It is glowing states of matter.

⇒ **Forms of Solid:**

Solids are divided into two classes on the basis of haphazard and regular arrangement of the building constituents.

Crystalline solids	*Amorphous solid*
Definite and regular geometry due to definite arrangement of particles (Atom, ion and molecules)	The term 'amorphous' has been derived from a Greek word 'Omorphe' meaning shapeless. Do not have definite geometry because have no definite arrangement of particles.
Sharp melting points	Do not have sharp melting points.
Anisotropic (some of there properties are different in different directions)	Isotropic (have same properties in all directions)
True solids	Pseudo-solids, or super cooled solids.
Rigid	Not very rigid.
Bound by plane faces	Do not have well defined planes
When it is broken it breaks up into smaller crystals of same geometrical shape.	The surfaces of the broken pieces are not flat and intersect at random angles.

	Asymmetrical.
They have symmetry.	Don't have a long-range order of atoms, ions and molecules.
Have long range order.	

⇒ ***Crystal lattice:*** the two- or three-dimensional arrangement on which atoms or group of atoms is to be placed to form crystal is called lattice of that crystal.

⇒ ***Lattice point/Sight:*** it is that points of crystal lattice where atoms or group of atoms is to be put

⇒ ***Basis:*** basis are those atoms or groups of atoms which are to be put on lattice.

⇒ Note that the combination of Basis (Atoms or groups of atoms) with Lattice (skeleton of crystal) form complete crystal.

$$Basis(\ Atoms\ or\ groups\ of\ atoms) + Lattice(Skeleton) \rightarrow Complete\ crystal$$

⇒ ***Lattice constants***: It is length or distance between basis or lattice points.

⇒ ***Translational vector or Basis vector:*** it is a position vector which locate atoms or group of atoms w.r.t to some reference points. This vector gives us displacement between basis.

⇒ ***Unit cell:*** A space lattice can be subdivided into a number of small cells known as unit cells.
It can be defined as the smallest repeating unit in space lattice which, when repeated over and over again, results in a crystal of the given substance.
it is the smallest block or geometrical figure from which entire crystal can be built up by its translational repetition in three-dimensions.
A unit cell of a crystal possesses all the structural properties of the given crystal for example, if a crystal is a cube, the unit cell must also have its atoms, molecules or ions arranged so as to give a cube.

⇒ In various unit cells, there are three kinds of lattice points: points located at the comers, points in the face-centers and points that lie entirely within the unit cell. In a crystal, atoms located at the comer and face-center of a unit cell are shared by other cells and only a portion of such an atom actually lies within a given unit cell.

⇒ A point that lies at the comer of a unit cell is shared among eight-unit cells and. therefore, only one-eighth of each such point lies within the given unit cell.

⇒ A point along an edge is shared by four-unit cells and only one-fourth of it lies within anyone cell

⇒ A face-centered point is shared by two-unit cells and only one half of it is present in a given unit cell

⇒ A body-centered point lies entirely within the unit cell and' contributes one complete point to the cell.

Types of lattice points	contribution to one-unit cell
Corner	$\frac{1}{8}$
Edge	$\frac{1}{4}$
Body-center	1
Face-center	$\frac{1}{2}$

Property	Simple cubic Unit cell	Body centered cubic	Face centered cubic
Location of points	Only at the corners of each units	Points are at the corners as well as in the body center of each cube.	Points are at the corners as well as the center of each of the six faces of the cube
Contribution of atoms per unit cell (Lattice points per cell)	Since, each comer atom is shared by eight surrounding cubes, therefore, it contributes for $\frac{1}{8}$ of an atom. $8 \times \frac{1}{8} = 1$ atom per unit cell	Since, the structure possesses 8 comer atoms and one body-center. the contribution will be $= 8 \times \frac{1}{8} + 1$ $= 2 \frac{atoms}{unit\ cell}$	Since, the structure possesses 8 comer atoms and six at the center of each face. the contribution will be $= 8 \times \frac{1}{8} + 6 \times \frac{1}{2}$ Because Face atom is shared by two cubes) $= 1 + 3 = 4 \frac{atoms}{unit\ cell}$
Atoms in single unit	8 atoms (center is empty)	9 atoms	14 atoms

Co-ordination number (Number of nearest neighbors)	6	8	12
Number of second neighbors	12	6	6

Stress

⇒ As we know that every solid have elasticity (will be explained later) up-to some extent which try to return the body to its original state when some deforming force is applied to it.

⇒ This internal restoring force per unit area is called stress.

⇒ In equilibrium the internal restoring force is equal in magnitude to external deforming force, for this case the stress maybe defined as;

"External force per unit area that try to deform the body".

⇒ if this external force is applied on a body of area 'A' then stress is given by;

$$Stress = \frac{Force}{Area} = \frac{F}{A} = \frac{N}{m^2}$$

⇒ Units: N/m^2(SI), $dyne/cm^2$ (CGS).

⇒ **Different types of stress:** *The change in configuration can be a change either in length, volume or shape of a body. There are three types of stress.*

1) ***Normal stress (Longitudinal stress):*** the intensity of internal force is perpendicular to or normal to a section is called normal stress.
   It is also termed as axial stress and occur only in solids.
   Types of normal stress
   ✓ ***Tensile stress:*** if there is an increase in length or extension of a body in the direction of force applied.
   ✓ ***Compressive stress:*** Longitudinal stress produced due to decrease in length of a body under a deforming force is called compressive stress.
2) ***Volumetric or Bulk stress:*** when a solid body undergoes a change in volume without any change in its geometrical shape on applying the force perpendicular to every point on the surface of a body. In this case the deforming force acts on the body from all sides.
3) ***Shear or Tangential stress:*** when a deforming force acting tangentially or parallel to the surface of a body produces change in the shape of the body without bring any change in volume the stress in this case is called shearing or tangential stress.

Difference between Stress and Pressure

Stress	Pressure
Stress can be normal or tangential to area.	Always normal to area.
Always compressive.	Maybe compressive or tensile.

Strain

⇒ The ratio of change in configuration (shape/length/Area of body) to original configuration (shape/Length/Area of body).

$$Strain = \frac{change\ in\ configuration}{original\ configuration}$$

⇒ It is the ratio of two like quantities so having no units.

Different types of strain:

1) ***Linear Longitudinal Tensile strain:*** when the deforming force causes change in length of the body. It is defined as the ratio of change in length to the original length of a body.

$$Linear\ strain = \frac{Change\ in\ length}{original\ length} = \frac{\Delta l}{l}$$

2) **Volumetric strain:** If the deforming force produces a change in volume alone the strain produced in the body is called volumetric strain.

$$Volume\ strain = \frac{Change\ in\ volume}{original\ volume} = \frac{\Delta V}{V}$$

3) **Shearing strain:** If the deforming force produces a change in the shape of the body without changing its volume, strain produced is called shearing strain.
It can be also defined as the ratio of displacement of a surface under a tangential force to the perpendicular distance of the displaced surface from the fixed surface.

$$Shearing\ strain, \theta = \frac{\Delta L}{L}.$$

Mechanical Properties of Solids

Strength: The ability of a material to endure larger impact forces without breaking.

Hardness: it is the measure of how easily can be scratched or Indented (to cut).

$$Hardness \propto Brittlness$$

Example: Diamond, hardened high carbon steels.

Brittleness: the ability of a body to resists against the plastic deformations.

Example: Concrete, cast iron, ceramics, and polymers such as urea formaldehyde.

Toughness: the material which can absorb the large impact of forces.

Plasticity: The property of matter by virtue of which it does not regain its original shape and size after the removal of deforming force is called plasticity.

Elasticity: The property of matter by virtue of which a body tends to regain its original shape and size after the removal of deforming force is called elasticity.

Stiffness: the capability of a body due to which it resists bending.

Ductility: the property of a body due to which it can be bent, squeezed or rolled in to wire.

$$Ductility \propto Plasticity$$

Factors Affecting Elasticity

⇒ Hammering and rolling: Crystal grains break up into smaller units by hammering and rolling. This results in increase in the elasticity of material.

⇒ Annealing: The metals are annealed by heating and then cooling them slowly. Annealing results in decrease in the elasticity of material.

⇒ Temperature: Intermolecular forces decreases with rise in temperature. Hence the elasticity decreases with rise in temperature but the elasticity of invar steel (alloy) does not change with change of temperature.

⇒ Impurities: Due to impurities in a material, elasticity can increase or decrease. The type of effect depends upon the nature of impurities present in the material.

Some important definitions:

1) ***Perfectly elastic body:*** If on the removal of deforming forces the body regain its original configuration completely it is said to be perfectly elastic.
100% perfectly elastic body is not possible.
A quartz fiber and phosphor bronze (an alloy of copper containing 4% to 10% tin, 0.05% to 1% phosphorus) is the nearest approach to the perfectly elastic body.

2) ***Perfectly plastic body:*** If the body does not have any tendency to recover its original configuration, on the removal of deforming force, it is said to be perfectly plastic.
100% perfectly plastic body is not possible.
Paraffin wax, wet clay is the nearest approach to the perfectly plastic body.

3) ***Elastic fatigue:*** The temporary loss of elastic properties because of the action of repeated alternating deforming force is called elastic fatigue.

4) ***Elastic after effect:*** The time delay in which the substance regains its original condition after the removal of deforming force is called elastic after effect.

5) ***Creep:*** the gradual increase in strain which occurs when a material is subjected to stress for a long period of time is knowns creep.

6) ***Elastic limit:***

- ✓ The maximum stress from which elastic body will recover its original state after the removal of the deforming force is called elastic limit.
- ✓ Every solid has certain range through which it may be deformed and yet returns to its original condition before its elastic limit is reached.
- ✓ The elastic limit is very high for a substance like steel and low for a substance like lead.
- ✓ Elastic limit is the property of a body whereas elasticity is the property of material of the body.

Hooke's Law and Modulus of elasticity

⇒ This law states that within elastic limit the extension produced in wire is directly proportional to the applied force.

$$Force \propto Extension \Rightarrow F \propto x$$

⇒ As we know that stress if measure of deforming force and strain is measure of distortion (extension) so we can state Hooke's law as;

$$Stress \propto Strain \Rightarrow \frac{Stress}{Strain} = Constant = Modulus\ of\ elasticity\ (E)$$

⇒ The constant of proportionality is known as modulus of elasticity and is different for different materials.

⇒ ***The modulus of elasticity depends upon;***

- ✓ Nature of material
- ✓ Type of deformation involved
- ✓ Temperature of the body

⇒ Its value is independent of the dimensions (length, volume etc.) of the body.

⇒ Greater the modulus of elasticity of a ma erial body the harder is to change its shape, size etc.

⇒ Unit of modulus of elasticity: as we know that strain have no unit so 'E' has same unit as that of stress. i.e. N/m^2

⇒ Modulus of elasticity is also measured in terms of pascal. ($1\ Pa = 1N/m^2$)

⇒ Dimension: $[ML^{-1}T^{-2}]$

Types of modulus of elasticity

1) Young's modulus of elasticity
2) Bulk modulus of elasticity
3) Shear modulus of elasticity

1) Young's modulus of elasticity:

⇒ It is defined as the ratio of normal stress to longitudinal strain within limit of proportionality.

$$Young's\ modulus = \frac{Normal\ stress}{Longitudinal\ strain} = \frac{Force/Area}{change\ in\ length/original\ length} = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$$

⇒ If 'r' is the radius of the wire then $A = \pi r^2$

$$Y = \frac{FL}{\pi r^2 \Delta L}$$

⇒ If force is applied on a wire of radius r by hanging a weight of mass 'm', then;

$$Y = \frac{mgL}{\pi r^2 \Delta L}$$

⇒ If the length of a wire is doubled,

$$Then\ longitudinal\ strain = \frac{Change\ in\ length(\Delta L)}{Initial\ length(L)} = \frac{Final\ length - Initial\ length}{Initial\ length} = \frac{2L - L}{L}$$

Which is equal to 1.

So, if length of a wire is doubled then strain produced is equal to 1.

$$\therefore Y = \frac{stress}{strain} \Rightarrow Y = \frac{stress}{1} \Rightarrow Y = stress$$

So, young's modulus is numerically equal to the stress which will double the length of a wire.

⇒ The increment in length is given by;

$$Y = \frac{FL}{A\Delta L} \Rightarrow \Delta L = \frac{FL}{\pi r^2 Y}$$

This equation implies that if same stretching force is applied to different wires of same material,

$$\Delta L = \frac{L}{r^2} \quad [As\ F\ and\ Y\ are\ constant]$$

So, elongation in wire is directly proportional to the ratio of $\frac{L}{r^2}$.

⇒ Elongation in a wire by its own weight: The weight of the wire mg act at the center of gravity of the wire so that length of wire which is stretched will be L/2.

$$\Delta L = \frac{FL}{AY} = \frac{mg\left(\frac{L}{2}\right)}{AY} = \frac{mgL}{2AY} = \frac{L^2 dg}{2Y} \qquad [as\ mass, m = volume \times density \Rightarrow AL \times d]$$

⇒ the elongation produced in wire is equivalent to the case when a rod of length 'L' is being pulled with two equal and opposite forces, each of magnitude F/2. Since, the rod is being pulled by a single force, therefore, deformation in the rod reduces to one-half.

⇒ Thermal stress: If a rod is fixed between two rigid supports, due to change in temperature its length will change and so it will exert a normal stress (compressive if temperature increases and tensile if temperature decreases) on the supports. This stress is called thermal stress.

⇒ Force constant of wire: Force required to produce unit elongation in a wire is called force constant of material of wire. It is denoted by k.

$$\therefore k = \frac{F}{\Delta L}$$

As from the definition of young's modulus,

$$\frac{F}{\Delta L} = \frac{YA}{L} \Rightarrow so, k = \frac{YA}{L}$$

It is clear that the value of force constant depends upon the dimension (length and area of cross section) and material of a substance.

2) Bulk modulus of elasticity (Elasticity in volume):

⇒ Bulk modulus refers to the change in bulk (volume) of a substance. i.e. solid and fluids (liquids and gases).

⇒ It is the ratio of normal stress to volumetric strain.

⇒ Denoted by 'k'.

$$K = \frac{Normal\ stress}{volumetric\ strain} \Rightarrow \frac{F/A}{-\Delta V/V} \Rightarrow k = -\frac{FV}{A\Delta V}$$

⇒ V is original volume and ΔV is change in volume.

⇒ The negative signs indicate that volume decreases with increase in pressure (stress).

⇒ As $\frac{Force}{Area} = \Delta P$ the increase in pressure on body is given by;

$$\therefore k = -V\frac{\Delta P}{\Delta V}$$

⇒ The Si unit of bulk modulus is N/m^2 or Pa.

⇒ the bulk moduli of solid and liquid are very large indicating the fact that large force is needed to produce even minute change in volume.

⇒ Gases are more easily compressed and have small bulk moduli.

- **Compressibility:** the reciprocal of bulk moduli is called compressibility.
  "it can be also defined as, compressibility is a measure of how easily the material is compressed".

$$Compressibility, k = \frac{1}{K}$$

✓ The Si unit of compressibility is $N^{-1}m^2$ or Pa^{-1}.

✓ Solids and liquids are relatively incompressible. (have small value of compressibility or large value of bulk moduli). In case of solids and liquids these values are independent of temperature and pressure.

✓ Gases are highly compressible. (small K and large k). incase of gases these values depend on pressure and temperature.

3) Shear modulus of elasticity (Elasticity of shape):

⇒ Within limits of proportionality, the ratio of tangential stress to the shearing strain is called modulus of rigidity of the material of the body.

⇒ It is denoted by η.

$$\eta = \frac{Tangential\ stress}{Tangential\ strain}$$

⇒ In this case the shape of a body changes but its volume remains unchanged.

⇒ Consider a rectangular block, if we apply tangential force on its upper face of the block. The force provides a shear stress which displaces the upper face through a small distance $AA' = \Delta L$.

$$if\ AF = L\ and\ area\ of\ the\ upper\ face\ is\ A, then;$$

$$Tangential\ stress = \frac{Force}{Area}$$

$$Shear\ strain = \theta = \tan\theta = \frac{AA'}{AF} = \frac{\Delta L}{L}$$

$$\eta = \frac{F/A}{\Delta L/L} \Rightarrow \frac{FL}{A\Delta L} \Rightarrow \frac{FL}{A\Delta L}$$

⇒ Si unit of shear modulus is N/m^2 or Pa.

⇒ The shear modulus has significance only for solid materials.

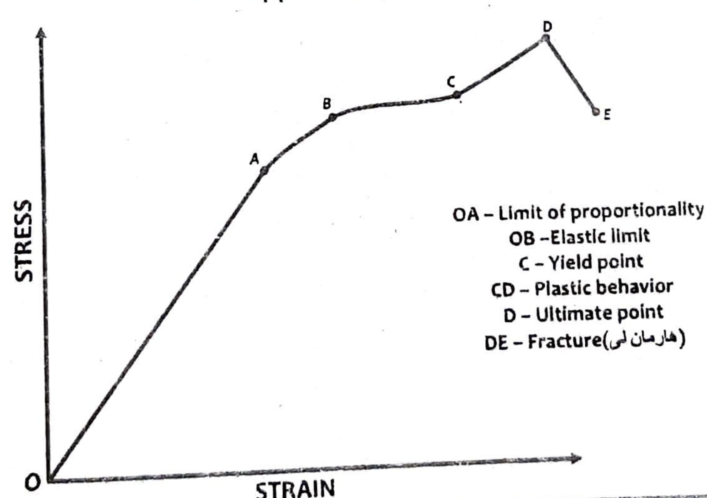
⇒ A liquid or gas flows under the influence of a shear stress and cannot support such stress.

⇒ NOTE: Shear modulus is roughly One-Third the value of young's modulus for the same solid material.

Stress-strain Curve

⇒ When a wire is stretched by a load, it is seen that for a small value of load, the extension produced in the wire is proportional to the load. On removing the load, the wire regains to its original length. The wire regains its original dimension only when;

$$Load\ applied \leq Elastic\ limit$$



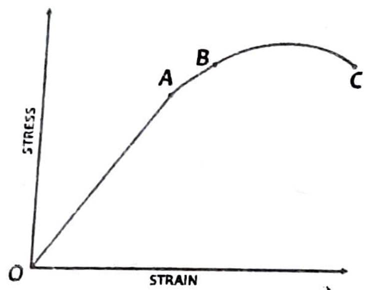
Region	Description
OA	For small stress, *the stress* $\propto$ *Strain*, i.e. in the region OA, this is the region where Hooke's law is truly obeyed. The point A is called limit of proportionality. Note: Slope of line OA gives us Young's modulus of the material of the wire. $if\ \theta\ is\ the\ angle\ of\ OA\ from\ strain\ axiss\ then\ Y = \tan\theta$
OB	For further increase in stress, the Hooke's law is not truly obeyed. However, the wire regains its original dimension after removal of stress. This is known as elastic limit.
C	If the wire is stretched beyond this limit, i.e. BC the strain increases much rapidly and if the stress is removed the wire does not come back to its original length. Some of the permanent increase in length also takes place.
CD	It is the region where small increase in stress produce many more strain (change) and the change is

	permanent. (plastic behavior)
D	This is the point where the plastic behavior also dies and for further increase in stress no increment in length is observed.
DE	At this point the any more stress applied results in fracture of the wire.

Some important points:

1) *The region OAB is called elastic region.*
2) *The region CDE is called Plastic region.*
3) *In the yield region, stress is 15-20 times those takes place up to the proportional limit occurring during yielding.*
4) *A study of Stress-Strain diagram shows that the yield point is so close to the elastic limit that for most purposes the two.*
5) *Breaking strain is constant for a material.*

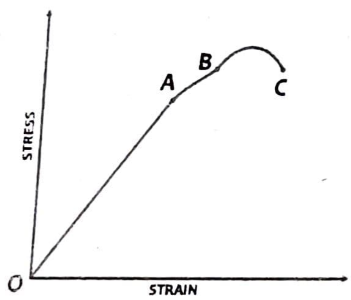
Stress strain curve for different materials



Ductile Material

The material of the wire has a good plastic range and such materials can be easily changed into different shapes and can be drawn into thin wires

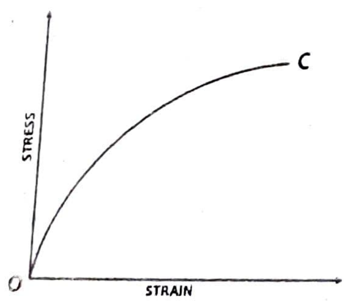
Example. Mild steel



Brittle Material

The plastic region between B and C is small for brittle material and it will break soon after the elastic limit is crossed.

Example : Glass, cast iron.



Elastomers

Stress-strain curve is not a straight line within the elastic limit for elastomers and strain produced is much larger than the stress applied. Such materials have no plastic range and the breaking point lies very close to elastic limit.

Example rubber

Work Done in Stretching a Wire/Strain energy/Elastic potential energy

⇒ When a body is strained, work has to be done to deformed the body. The work is stored in the body in the form of elastic strain energy.

⇒ So, the work done when a wire is stretched results in energy being stored in it is called strain energy.

⇒ The strain energy stored in unit volume of an elastic body is called strain energy per unit volume.

Strain energy (U)	Strain energy per unit volume (U_v)
$\frac{1}{2}Fl$	$\frac{1}{2}\frac{Fl}{Volume}$
$\frac{1}{2}\times Stress \times Strain \times Volume$	$\frac{1}{2}\times Stress \times Strain$

$\frac{1}{2}\times Y\times(Strain)^2\times Volume$ $\frac{1}{2Y}\times(Stress)^2\times Volume$	$\frac{1}{2}\times Y\times(Strain)^2$ $\frac{1}{2Y}\times(Stress)^2$

⇒ If the force on the wire is increased from F_1 to F_2 and the elongation in wire is l then energy stored in the wire;

$$U=\frac{1}{2}\frac{(F_1+F_2)}{2}l$$

Electrical properties of material

⇒ Those properties of a material due to which its responds to external electric field.

⇒ Electrical properties are explained by Electron sea theory.

⇒ According to electron sea theory, "Electrons of one atom can move into another atom". According to this theory Conductivity is due to free electrons present in atom.
Failure: this theory cannot explain the nature of Semi-conductor and insulator.

⇒ Substances are divided into three types on the basis of their electrical nature/Properties.

Conductor	A substance which allow current to pass easily through it, or A substance having free electrons.
Insulator	A substance which does not allow current to pass through it. Have no free electrons.
Semi Conductor	Those substance whose properties are in between conductors and insulators. At 0 kelvin or at absolute zero temperature the semi-conductor act as insulator. Above zero kelvin temperature they behave as conductor.

⇒ **Specific Resistivity:**

$$\rho_{Insulator}>\rho_{semi-conductor}>\rho_{conductor}$$

⇒ **Conductivity:**

$$C_{Conductor}>C_{semi-conductor}>C_{Insulator}$$

Energy Band theory

⇒ This theory is based on the Pauli exclusion principle.

⇒ This theory explains the conductor, Insulator and semi-conductor materials.

⇒ Before going towards the statement of this theory, we have to quickly review some terminologies.

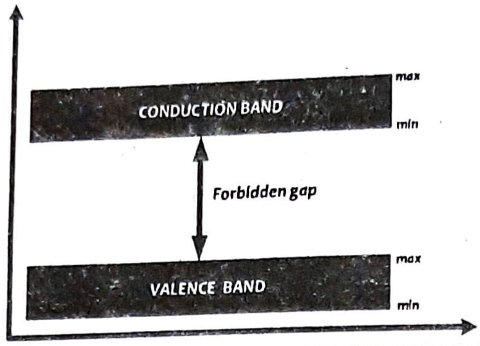
Isolated Atom
✓ An atom having no interactions with other atoms.
Valence Shell/Valence Band
✓ The outermost shell where electrons are presents in their ground state. (Un excited state) ✓ Above the valence shell further shell exists but generally they are empty. ✓ Never empty. ✓ It is completely or partially filled. ✓ Valence band is highest occupied. ✓ This is the band of maximum energy. ✓ Electrons are not capable of gaining energy from external electric field. ✓ No flow of current due to electrons present in this band. ✓ The highest energy level which can be occupied by an electron in valence band at 0 K is called fermi level.
Conduction Band
✓ The higher energy level band. ✓ It is also called empty band of minimum energy. ✓ This band is partially filled by the electrons. ✓ In this band the electrons can gain energy from external electric field. ✓ The electrons in the conduction band are called the free electrons. ✓ They are able to move any-where within the volume of the solid. ✓ Current flows due to such electrons.
Allowed Region/Shells/Energy Levels/Orbits
✓ The region where electrons can exist. ✓ In that region (K, L, M, N) has a specific energy so that's why it is called energy level.
Forbidden gap/Region

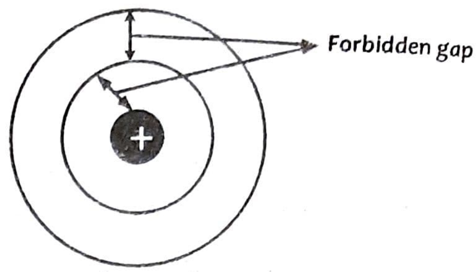
- ✓ Energy gap between conduction band and valence band.

$$\Delta E_g = (C.B)_{min} - (V.B)_{max}$$

- ✓ The region where free electron cannot exist.
- ✓ This region exists between Orbits and shells.
- ✓ Width of forbidden energy gap depends upon the nature of substance.

$$Temperature \propto \frac{1}{Forbidden\ gap}$$





An Atom

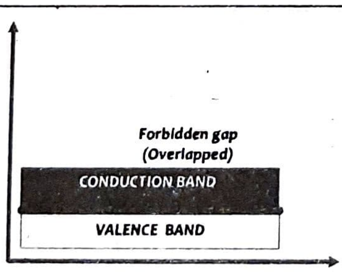
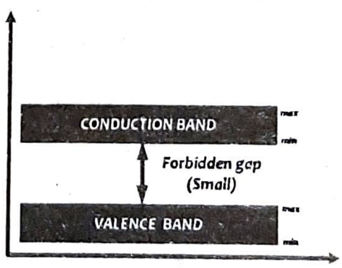
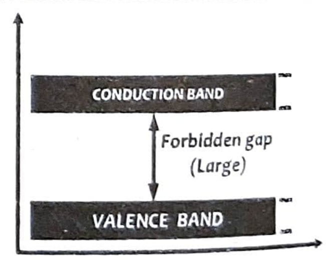
Splitting Of Energy Level

- ✓ When an atom brought close to any other atom than energy level will splits into sub energy level.

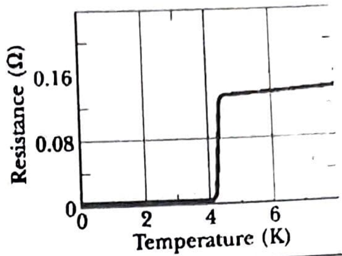
Note that Concept of Energy Band theory is based on Splitting of energy levels.

⇒ *In isolated atom the valence electrons can exist only in one of the allowed orbitals each of a sharply defined energy called energy levels. But when two atoms are brought nearer to each other, there are alterations in energy levels and they spread in the form of bands.*

⇒ *On the Basis of Energy band theory, we can easily explain Conductor, semi-conductor and Insulators.*

Properties	Conductor	Semiconductor	Insulator
Electrical Conductivity	10^2 to $10^8 \Omega m$	10^{-5} to $10^0 \Omega m$	$10^{-8} \Omega m$
Resistivity	10^{-2} to $10^{-8} \Omega m$	10^5 to $10^0 \Omega m$	$10^8 \Omega m$
Energy Gap	Zero or very small	Ge → 0.7 eV Si → 1.1 eV GaAs →1.3 eV GaF_2 → 2.8 eV	Very large; for diamond it is 6 eV
Band structure			
Current carriers	Free electrons	Free electrons and holes	– –
Condition of valence band and conduction band at ordinary temperature	V.B. and C.B. are completely filled or C.B. is somewhat empty	V.B. – somewhat empty C.B. – somewhat filled	V.B. – completely filled C.B. – completely unfilled
Temperature co-efficient of Resistance	Positive	Negative	Zero
Effect of temperature on	Increases	Decreases	– –

resistance			



Effect of temperature on conductivity	Decreases	Increases	— —
Examples	*Cu, Ag, Au, Na, Pt, Hg etc.*	*Ge, Si, Ga, As etc.*	*Wood, plastic, mica, diamond, glass etc.*

Superconductors

⇒ Superconductors are materials with a resistivity of zero.

⇒ In 1911, Dutch physicist Kamerlingh Onnes discovered that the resistivity of mercury absolutely disappears at temperatures below about 4 K.

⇒ This phenomenon of superconductivity is of vast potential importance in technology because it means that charge can flow through a superconducting conductor without losing its energy to thermal energy.

⇒ Superconductivity is a phenomenon much different from conductivity.

⇒ In fact, the best of the normal conductors, such as silver and copper, cannot becomes superconducting at any temperature, and the new ceramic superconductors are actually good insulators when they are not at low enough temperatures to be in a superconducting state.

⇒ We define the temperature at which and below which a material becomes a superconductor to be its critical temperature, denoted by T_c.

Magnetic properties of a substance

⇒ The property of a material due to which it responds to external magnetic field.

⇒ The cause of magnetic field is moving charges, so moving charges behave as a magnet.

⇒ Matter is composed of atoms while atom is composed of electron, proton and neutron.

⇒ The spinning motion of electron and proton are responsible for magnetic properties.

⇒ ***Magnetic field due to motion of electron:***

Motion of electron is of two types;

1) Orbital motion: orbital motion of electron produce strong magnetic field.
2) Spin motion: Spin motion of electron produces weak magnetic field.

Note: *The magnetic field produce due to orbital motion is two (2) times the magnetic field produce to spin motion.*

⇒ Magnetic field due to motion of proton:

Have only spin motion and produce very week magnetic field.

⇒ Note that magnetic properties of atom are mainly due to orbital motion of electrons.

⇒ Orbital motion of electron is just like current loop and current loop behave as a bar magnet.

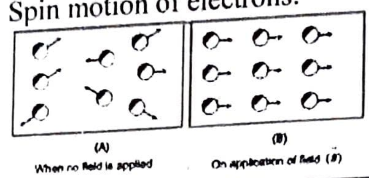
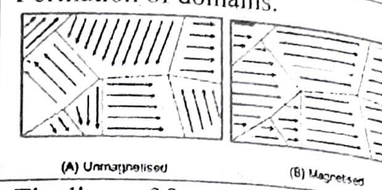
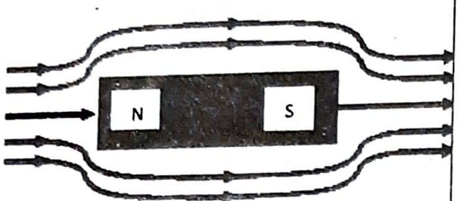
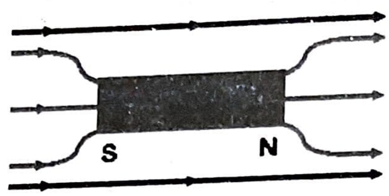
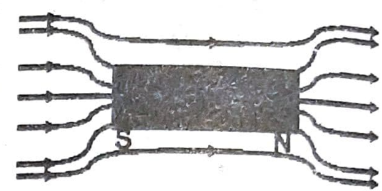
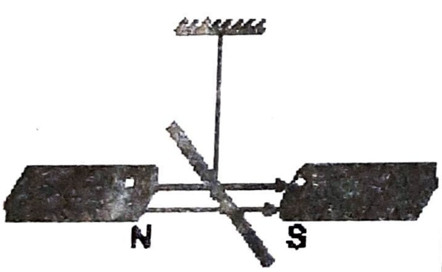
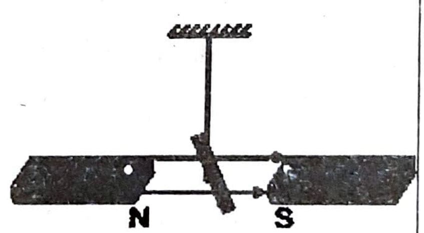
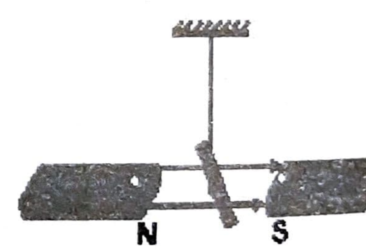
⇒ Atom is sometime called tiny small magnet.

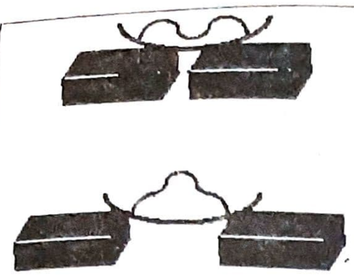
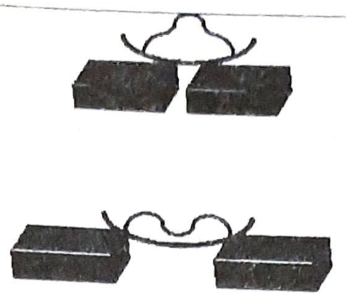
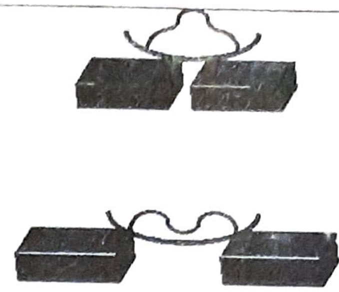
⇒ Note: *if Two electrons move in opposite direction, they can cancel out the magnetic field of each other.*

⇒ Magnetic field of electron and proton sometime become parallel to each other, they reinforce to effect of each other, this time they produce strong magnetic field which is sometime called magnetization.

⇒ On the basis of magnetic properties substances are divided into three groups;

1) Diamagnetic
2) Paramagnetic
3) Ferromagnetic

DIAMAGNETIC	PARAMAGNETIC	FERROMAGNETIC
Diamagnetic substances are those substances which are feebly repelled by a magnet. Diamagnetism is the intrinsic property of every material. Example: Antimony, Bismuth, Copper, Gold, Silver, Quartz, Mercury, Alcohol, water, Hydrogen, Air, Argon, etc.	Paramagnetic substances are those substances which are feebly attracted by a magnet. Example: Aluminum, Chromium, Alkali and Alkaline earth metals, Platinum, Oxygen, etc.	Ferromagnetic substances are those substances which are strongly attracted by a magnet. Example: Iron, Cobalt, Nickel, Gadolinium, Dysprosium, etc.
Orbital motion of electrons is cause of magnetism.	Spin motion of electrons. 	Formation of domains. 
When placed in magnetic field, the lines of force tend to avoid the substance 	The lines of force prefer to pass through the substance rather than air. 	The lines of force tend to crowd into the specimen. 
When placed in non-uniform magnetic field, it moves from stronger to weaker field (feeble repulsion).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (feeble attraction).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (strong attraction).
When a diamagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction perpendicular to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field. 	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field very quickly. 
If diamagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects away from the center when the magnetic poles are closer and collects at the center when the magnetic poles are farther.	If paramagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the center when the magnetic poles are closer and collects away from the center when the magnetic poles are farther.	If ferromagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the center when the magnetic poles are closer and collects away from the center when the magnetic poles are farther.

		
When a diamagnetic substance is placed in a magnetic field, it is weakly magnetized in the direction opposite to the inducing field.	When a paramagnetic substance is placed in a magnetic field, it is weakly magnetized in the direction of the inducing field.	When a ferromagnetic substance is placed in a magnetic field, it is strongly magnetized in the direction of the inducing field.
Intensity of Magnetization (I) has a small Negative value.	Intensity of Magnetization (I) has a small Positive value.	Intensity of Magnetization (I) has a large Positive value.
Magnetic permeability μ $\mu<1$	$\mu > 1$	Magnetic permeability μ is large $\mu \gg 1$
Magnetic susceptibility cm has a small Negative value.	Magnetic susceptibility cm has a small Positive value.	Magnetic susceptibility cm has a large Positive value.
their properties do not change with temperature. i.e. They do not obey Curie's Law.	They lose their magnetic properties with rise in temperature. They obey Curie's Law.	At a certain temperature called Curie Point, they lose ferromagnetic properties and behave like paramagnetic substances. They obey Curie's Law.

Magnetization/Magnetization field/Magnetic moment

⇒ The process in which material is magnetized is called magnetization.

⇒ The external magnetic field used to magnetize a material is called magnetization field.

⇒ The movement of a tiny magnets/Atomic magnets with respond to external magnetic field.

⇒ Atom behave like a bar magnet and have two poles. {NOTE: Monopole of magnet does not exist}.

Intensity of magnetizing field (magnetizing field):

⇒ It is the degree or extent to which a magnetic field can magnetize a substance.

⇒ Represented by $'H'$.

⇒ Note that, $H \propto I(Magnetization\ current) \rightarrow H = KI(k - constant)$

⇒ **Mathematically**: $H = \frac{B}{\mu_o}$

$$\Rightarrow B = H \times \mu_o$$

$$As\ \phi = BA \rightarrow B = \frac{\phi}{A}(we\ can\ also\ express\ it\ in\ this\ form\ by\ putting\ \vec{B}\ in\ equation)$$

$$Note\ that, \vec{B} = Magnetic\ flux\ density$$

$$As\ B \propto H(B \rightarrow Magnetization\ , H \rightarrow Magnetizing\ field)$$

⇒ **Unit**: $H = \frac{B}{\mu_o} \rightarrow \frac{N}{m^2 \times tesla} = \frac{N}{wb} = \frac{J}{m^3 \times Tesla} = \frac{J}{m \times weber}$

Hysteresis:

⇒ Hysteresis mean energy loss.

⇒ The close loop formed by magnetization and demagnetization.

⇒ It may be defined as, "The lagging of induce magnetization in a material from magnetization field is known as hysteresis".

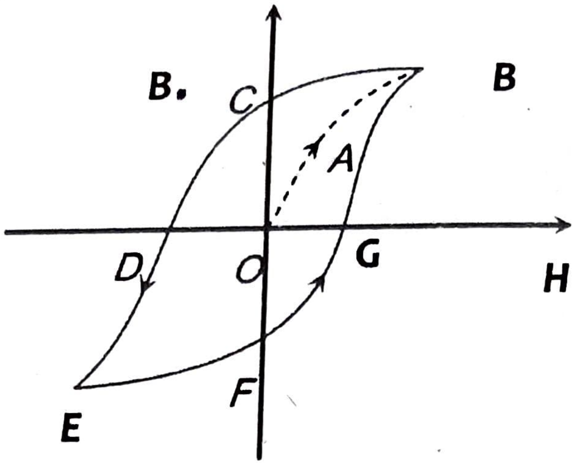
⇒ The phenomena of lagging of flux density (B) behind the magnetizing field (H) in a magnetic material subjected to a cycle of magnetization is called magnetic hysteresis.

⇒ We know that when we pass a current through a metal there some magnetic field is induced which depends upon current, as we increase magnitude of current the induce magnetic field also increase, incase if we stop our current the induce magnetic field also dies off.

⇒ Here in some materials we see some property like, if we pass current through a material the magnetic field induces after some time (lag behind current) in same case if the we stop the flow of current through a material then magnetic field dies off after some time of the stopping of current.

⇒ From this concept (i.e. lagging of induce magnetization behind magnetization field (current) a close loop can be constructed which is called hysteresis.

⇒ *Magntization field* $\propto$ *Current*.



Region	Description
$O \rightarrow B$	If the magnetization current, 'I' is increased in a positive then the magnetic field strength H also increases linearly with I and flux density B will also be increases. $I \neq 0$ $H \neq 0$ $B \neq 0$
$B \rightarrow C$	If the magnetizing current in the coil is reduced to zero, the magnetic field reduces to zero but the magnetic flux does not reach zero due to residual magnetism present within the core. $I = 0$ $H = 0$ $B \neq 0$
$C \rightarrow D$	To make the flux density zero at a point we need to reverse the current. The magnetizing force which we apply in this region (must be applied) is called "Coercive Force". $I = 0$ $H = 0$ $B = 0$
$D \rightarrow E$	If the reverse current is increased it causes the core to be magnetized in opposite direction. This point (E) is called saturation point.
$E \rightarrow F$	If the magnetizing current is reduced again to zero the residual magnetism present in the core will be equal to the previous value but in reverse.
$F \rightarrow G$	This region shows when we again reverse the flow of magnetizing current this time into a positive direction will cause the magnetic flux to reach zero. $I \neq 0$ $B = 0$

	$H \neq 0$

Some important points:

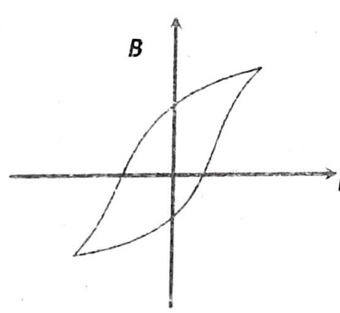
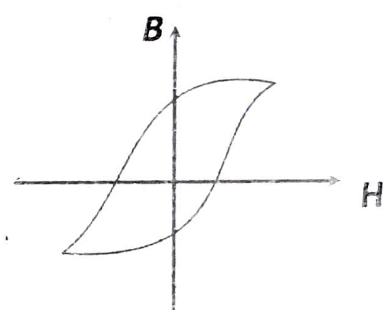
⇒ The region O-B-C-D-E-F-G form a close loop or cycle called hysteresis loop or cycle.

⇒ This cycle shows that when a magnetic material is subjected to one cycle of magnetization, 'B' always lags behind 'H'.

Some important definitions	
Coercivity (Qualitative)	The property of a material due to which a material lost induce magnetization with reverse magnetization field.
Coercive force (Quantitative)	The amount of reverse magnetic field which must be applied to a magnetic material to make magnetic flux returns to zero.
Retentivity	The material's ability to certain amount of residual magnetic field when the magnetizing force is removed after saturation.
Residual magnetism or Residual flux	The magnetic flux density (B) that remains in a material when the magnetizing force is zero.
Reluctance	It is the opposition that ferromagnetic materials show to the establishment of a magnetic field. It is analogous to the resistance in electrical circuit.

Mainly there are two types of materials

1) Soft materials
2) Hard materials

Properties	Soft materials	Hard materials
Area of Hysteresis loop	 Less	 Large
Energy loss	Low	High
Retentivity	Less	More
Coercive force	Less	More
Magnetic permeability	High	Low
How fast it magnetizes and demagnetizes	Can be magnetized and demagnetized easily	Cannot be magnetized and demagnetized easily
Uses	Used in dynamo, transformer, electromagnet tape recorder and tapes etc.	Used for making permanent magnet

Some important points and tricks

1) If a wire of length L is cut into two or more parts, then again, its each part can hold the same weight since breaking force is independent of the length of wire.
2) When equal deforming forces are applied on different bodies, then the body which shows less deformation is more elastic.
3) Hooke's law is obeyed only for small values of strain.
4) When the deforming force is inclined to the surface, both the tangential as well as normal stress are produced.
5) The area under the stress-strain graph gives the energy stored per unit volume.
6) Breaking stress for a wire of unit cross-section is called tensile strength.
7) Elasticity is meaningless for the rigid bodies. That is, elasticity is the property of non-rigid bodies.
8) Greater the value of Young's modulus of a material, larger is its elasticity.
9) Measure of deformation is strain.
10) The change in density for a given mass is same as change in volume.
11) Shear strain is actually the angle through which a regular body deviates when a parallel force is applied on it.
12) The modulus of elasticity depends upon the material of the body and not on the values of stress and strain.
13) Bulk modulus is defined for all types of materials: solids, liquids and gases.
14) Glass is more elastic than rubber.
15) Young s modulus and bulk modulus for a perfectly rigid body is infinity.
16) The total work done in stretching a wire is area under load-extension curve.
17) Stress is not scalar because it has different values in different directions.
18) Stress is not a vector quantity because it has no specified direction at a given point for different cross-sections.
19) The reason why we take average force and not the mass force is because the force goes on increasing from minimum value to maximum value.
20) Never keep the value of A in terms of r If given that r1 = 2r2, then just write A1 = 4A2.
21) If a wire can bear maximum force F, then wire of same material but double thickness can bear maximum force 4F, but breaking stress remains unchanged.
22) If two wires are joined, F1 = F2.
23) Breaking load = Breaking stress x Area of cross section. Breaking load will not depend on the length. For example, if a wire of 10 m can bear a maximum load of x newtons, then the same wire of 5 m also will bear the same load of x newtons.
24) Stress in a material is developed in two ways. If there is a change in length or volume, force is applied perpendicularly and if there is a change in shape, force is applied parallel.
25) When a body is sheared, two mutually perpendicular strains are produced. They are called longitudinal strain. Both are equal in magnitude.
26) If the length of a wire is doubled,

$$\text{then longitudinal strain} = \frac{2L - L}{L} = 1$$

$$Y = Stress \; [\because Strain = 1]$$

So, Young's modulus is numerically equal to the stress which will double the length of a wire.

27) If same stretching force is applied to different wires of same material, then $l \propto \frac{L}{r^2}$

$$[\because F \text{ and } Y \text{ are constant}]$$

Greater the ratio $\frac{L}{r^2}$ greater will be the elongation in the wire.

28) If the force on the wire is increased from F1 to F2 and the elongation in wire is l, then energy stored in the wire.

$$U = \frac{1}{2}\frac{(F_1 + F_2)}{2}l$$

29) Work done in stretching a wire $= \frac{F}{2}\left(\frac{FL}{AY}\right) = \frac{F^2 L}{2AY}$

FORMULAS SHEET

1.	Stress	$\sigma = \frac{Force}{Area}$	
2.	Strain	$Strain = \frac{\Delta L}{Original\ L}$	
3.	Volumetric strain	$V.S = \frac{Change\ in\ V}{Original\ V}$	
4.	Compressive strain	$\varepsilon = \frac{decrease\ in\ length}{Original\ length}$	
5.	Tensile strain	$\varepsilon = \frac{increase\ in\ length}{Original\ length}$	
6.	Modulus of elasticity	$E = \frac{Stress}{Strain}$	
7.	Young's modulus	$Y = \frac{Tensile/Compressive\ stress}{Tensile/Compressive\ strain}$	$Y = \frac{F/A}{\Delta l/l}$
8.	Bulk modulus	$K = \frac{Volumetric\ stress}{Volumetric\ strain}$	$K = \frac{F/A}{\Delta V/V}$
9.	Shear modulus	$G = \frac{Shear\ stress}{Shear\ strain}$	$G = \frac{F/A}{\tan\theta}$
10.	Strain energy	$U = \frac{1}{2}(F \times \Delta l)$	$U = \frac{1}{2}\left(\frac{EA \times (\Delta l)^2}{L}\right)$

UNITS

1.	Stress	Nm^{-2}	Pa
2.	Strain	No unit	
3.	Modulus of elasticity	Nm^{-2}	Pa